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CONSTRUCŢII. ARHITECTURĂ

TESTING AND EVALUATING THE STABILITY OF COATING SYSTEMS OF THE INTERIOR SHELLS IN COOLING TOWERS

BY

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Abstract. Natural draught cooling towers are exceptional structures in every respect. Due to the enormous surface in connection with the diverse range of impacts from surrounding environment and operation, interior shells of cooling towers require particular protection. This is achieved by applying special polymer-resin based coating systems, ensuring a high durability of the reinforced concrete structure, which in turn means increasing the service life and thus cost-effectiveness. So as to ensure the success of the coating project in terms of material properties and application, extensive quality assurance steps have been established, including primarily the testing of the dry layer thickness achieved and the adhesion of the system to the substrate.

Key words: cooling towers; polymer-resin; coating systems.

1. Introduction

There are nonetheless certain uncertainties as regards to obtaining data of the site, which depends on a large number of different parameters. In structures as exposed as natural draught cooling towers this leads in particular to frequent disputes and differing interpretations about the achieved results

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2. The Basics

Natural draught cooling towers as part of modern power plants are of great importance for a reliable energy supply. In addition to appropriate dimensioning, this also plays an important role in terms of operation and maintenance, as the large surface also means a large area to play out damaging attacks of environmental conditions and operational influences (Fig. 1). A detailed description of the complexity of cooling tower shells especially with regard to its impacts has already been given by Heine (2010).

Fig. 1 – Work platform in a natural draught cooling tower.

2.1. Impacts on and Protection of the Surface of Interior Shells in Cooling Towers

In terms of weather impact the exterior of the cooling towers is subjected to considerable temperature fluctuations. In addition, stresses from liquids that penetrate pore structure or cracks are present, as well as stresses caused by freeze/thaw cycles. In case of discharging cleaned flue gas, a chemical attack through acid condensation takes place.

The protective effect on the reinforced concrete structure is primarily based on the lasting resistance of the coating against chemical attack from acid condensation. Mechanical impacts may, however, also be an issue. An additional loading results from the combination of acid condensation and global or scattered radiation. The considerable changes in temperature may also lead to a deformation of the structure, which is to be permanently compensated by way of the coating used. Despite making the structure more flexible, in this way a high weathering and ageing resistance must be retained.

2.2. Bond – Importance and Testing

The coating system must be able to suit the impacts to be expected so as to avoid damage to the surface or at least delay such damage, thereby ensuring a sufficiently thick layer that will still provide long-term protection of the substrate.

Moreover, the bonding between the individual layers of the system and to the substrate is important as it safeguards functionality (Table 2). The bonding can be put to destructive test in an adhesive tensile test in accordance with Rili-SIB (2001). Hence, because of the local conditions, less destructive and less elaborate methods for the testing of coating systems in interior cooling tower shells are preferred.

The cross cut adhesion test in accordance with DIN EN ISO 2409 (2007) ought to be carried out using a multi-cutter tool or a cutter knife and a raster stencil. Here, 6 parallel cuts are made both vertically and horizontally, producing 25 individual squares. These are then taped off with masking tape, which is rapidly torn off at an angle of about 60°. In accordance with the new VGB guideline (issue 2010) a raster distance of 4 mm is prescribed. The number of spalled squares and damaged cut edges is the basis for a classification based on DIN EN ISO 2409 (2007).

The acute angle cutting test has not been made a standard test in terms of allowing an assertion as to the bonding behaviour, but is nonetheless widely used in practice, primarily because hardly any equipment is necessary for it. In the acute angle cutting test two cuts are made that cross at an angle of 30°. It is peeled off successively across the widening strip until it tears off.

3. Validity and Reliability of the Bonding Test

Within the scope of quality assurance the test results of the dry layer thickness measurements and bonding form the basis for an extensive statics evaluation and are therefore the basis for an evaluation of the protection measures taken.

From experience it can be seen that mainly adhesion test results that often leave plenty of room for interpretation and only present a reliable basis for evaluation if all relevant factors have been taken into consideration. Furthermore, not only the reliability of the test value alone, but also the limits of certain test methods under certain conditions are of importance.

4. Examination Programme and Test Parameters

The starting point is over 150 cooling tower projects realized by MC-Bauchemie worldwide. Based on this experience it seems necessary to achieve more accurate test and measuring results so as to enable more reliable statements to be made in practice as to the quality of a restoration.

The aspects of the bonding behaviour of coating systems identified as critical for the interior shells of cooling towers led to a diverse range of test series over a total time span of two years.

All series put together are the standard test method commonly used in practice, so that over this time span together with cases from practice a considerable amount of data was collated (Table 1).

Table 1
Variation of Test Parameters

Operator	Up to three different operators (person A / B / C): different experience and different use of force
Temperature	Constant temperature area between 20°C and 23°C One test series at 6°C
Substrate	Paving stones with different degrees of roughness: cleaned, blasted, high-water-jetting or with mineral levelling
Overworking interval	Depending on temperature and system between two hours and two weeks

Table 2
System Structures (Cooling-Tower-Specific High-Performance Systems in Accordance with VGB-Guideline (2010), either Rolled on or Sprayed)

Intermediate coat	Top coat
Epoxy	Epoxy
Epoxy	Polyurethane (UV protection)
Epoxy, water-based	Epoxy, water-based
Epoxy, water-based	Polyurethane (UV protection)
Water-based polyurethane sealing	Water-based polyurethane sealing

5. Results of Bond Testing

5.1. Cross Cut

a) *Cutting into the surface*

According to DIN EN ISO 2409, Section 3.2.1, the multi-cutter tool is not suitable for dray layer thicknesses larger than 120 µm, or for hard coatings and soft substrates. Practice has indeed shown even at moderate surface roughness that not all blades cut evenly and that the force required for six parallel incisions is too high (Fig. 3).

Performing the cross cut (with a cutter knife and stencil) is in principal workable as hardly any equipment is required and the test is easy to perform. Nonetheless, results still are dependent on who carries out the test, especially when increased force is necessary or when a high number of individual measurements have to be taken (loss of strength). Furthermore, even at moderate roughness of the surface there is the danger of making imperfect cuts after the grain peak (blade slides off) without noticing this straight away.

It was also observed that when running the blades over the surface the bonding of the adjacent coating alongside the fine filler damaged by the cut is being lost, which is having a detrimental effect on the results. The requirement to make an incision into the coating system right down to the substrate without this however damaging the substrate, may be the cause for considerable variations (Fig 2).

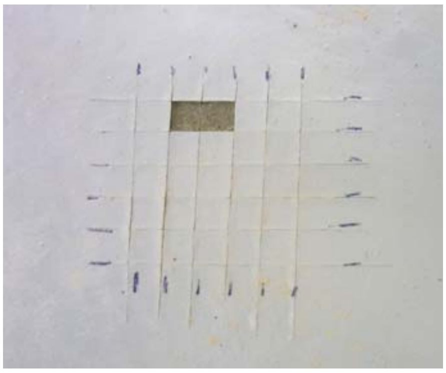

Fig. 2 – Cross cut (Gt2) with a multi-cutter tool.

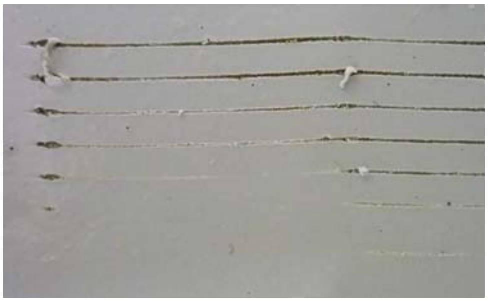

Fig. 3 – Failed attempt with a multi-cutter tool.

b) *Positioning and tearing off the masking tape*

In DIN EN ISO 2409 (2007) it is pointed out explicitly, that structured surfaces lead to results of excessive variation. The main reason for this is a not complete adhesion of the masking tape around and between raised points. The failure between masking tape and surface occurs disproportionately early.

The examinations have however shown that, in general, the bonding between masking tape and surface is an often underestimated factor. Despite there being explicit stipulations for the adhesive power of 2.40...4.00 N/cm (DIN EN ISO 2409, 2007), the bonding depends nevertheless heavily on the masking tape itself and on the surface condition of the coating system. This is heavily influenced by the individual components, primarily by additives such as film forming aids or defoamers (Fig. 4).

Furthermore it was identified that in a quantitative evaluation of the bonding behaviour also the age of the surface is playing a part in the peel-off power of the masking tape. In Fig. 5 it can be seen that in three out of four tested systems the peel-off force is greatly improved between the 1st and 3rd day (system 1: factor 3.2!), while in system 4 hardly any changes are detected.

In turn, these factors have of course a heavy impact on the results achieved with the cross cut (*e.g.* bad adhesion = above average good results). For the other examinations the tests were carried out using a standard masking tape (masking tape 1 and 2) on 3 to 5 days old smooth top coats. In practice it appears therefore to be at least appropriate to perform the cross cutting test on the top coat not before the third day after application (relating to approx. 20°C).

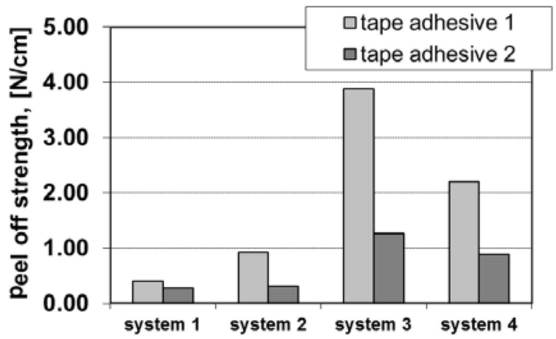

Fig. 4 – Dependence of the achieved peel-off force from the surface of various top coat materials and the masking tape used (age of top coat three days).

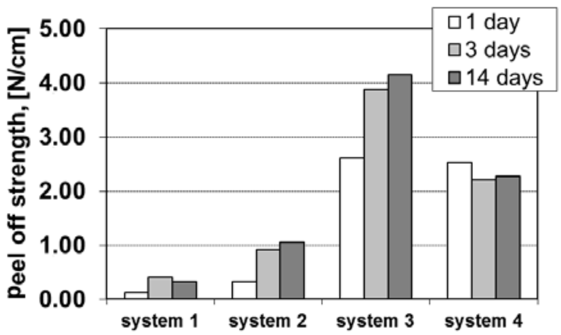

Fig. 5 – Influence of the age of the top coat on the peel-off force achieved.

c) *Results*

In practice many disagreements are caused by the fact that DIN EN ISO 2409, as a test standard, does make detailed stipulations as to how to perform the test (*e.g*. 23°C ± 2°C and 50% ± 5% rel. humidity), but that the broad range of applications alone – from varnishes to coatings – necessitates an "adjustment" to how they are performed and makes a general formulation necessary in parts (*e.g*. drying over the predetermined time span). It is pointed out that in a cross cutting test, as a field test the respective test framework conditions must be documented but without the need to address the possible effects on the test results or to take into consideration certain material properties.

The laboratory tests took place under consideration of the normative guidelines. Here it was found that the decisive influence on the result is the age of the coating system at the time the cross cutting test is performed. In practice the test is often carried out after one or two days. Frequently, in such tests it is not being considered that the bonding between the individual coats does continue to improve over the first few days. This is particularly noticeable in polyurethane systems that have a slower curing and bonding effect than EPs.

Fig. 6 shows a number of critical systems and their improvement potential by around 30% between day 2 and day 5 alone. Within the framework of an evaluation of over 100 tests it was also identified that the usual standard systems (both EP and PU) do generally no longer show any spalling as from day 3 (=G_{t0} or G_{t1}, after non-critical – Engelfried, 1996).

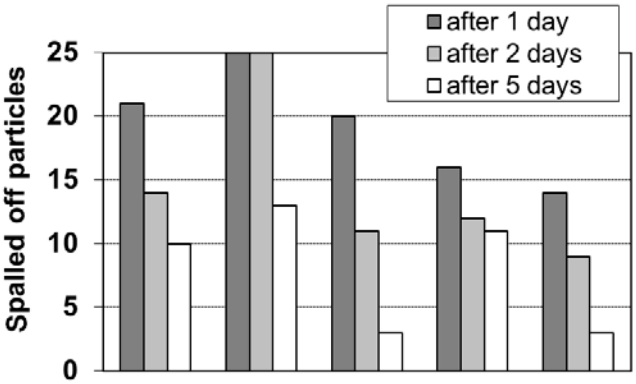

Fig. 6 – Improvement of the cross cut in dependence with the age of critical coating systems at the time of the test (20°C, 50% rel. humidity).

An evaluation about the success of a coating measure should only be made from day 3, better still from day 5 after application of the last layer (relating to approx. 20°C). When extrapolating this facts to 8°C a waiting period of 7 days is calculated, which, in practice, is virtually never adhered to.

Table 3
Waiting Time Until a Cross Cutting Test at Different Temperature

Temperature, [°C]	8	23	30
Age of the last top coat until testing the overall system through a cross cutting test, [days]	7	3	3

Especially in water-based systems it is potentially possible to determine the overworking interval for the interim coats, by way of performing a cross cutting test at a defined point in time after application of the last layer. In Fig. 7 one can see the bonding quality deteriorating as the 1st applied layer gets older. An overhaul of the 1st top coat is possible up to 5 days in these systems at 20°C, so that a bonding is achieved that meets the requirements of G_{t2} (age at the time of testing: 5 days).

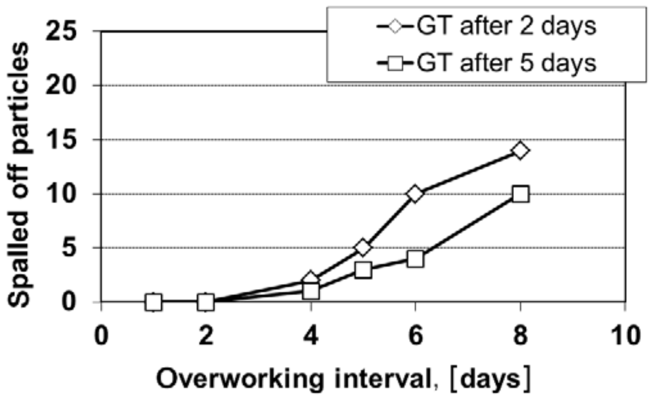

Fig. 7 – Cross cuts after 2 and 5 days (= constant), respectively, *vs*. the age of the 1st top coat before the 2nd top coat was applied (determining the overhaul window at 20°C and 50% relative humidity).

4.2. Acute Angle Cutting Attempt

a) *Execution*

When performing the acute angle cutting attempt the same limitations apply in principal as for the cross cutting test. Influences of the substrate (fine filler), the operator (force and handling when making the incision) *vs*. the system must be taken into consideration when evaluating the results achieved. Particularly important is here the roughness, as at localized thin layer thicknesses above grain peaks a tearing of the film is kind of provoked. A correct incision is also more difficult in this case. Normative guidelines for laboratory or practice tests do not exist for this, hence being possible to knowledge the influence of the different parameters is even more important.

This method is the only one that peels off rather than tears off. Here it is not the laminar adhesion (N/mm^2) which is evaluated, but the peel-off force (along a line, hence N/mm) which is subjected to peel-off resistance. One problem is the evaluation of the peeling off since a sensible grading for classification purposes does not exist.

b) *Results*

The systems to be tested were applied to a prepared substrate (in this case the back of a paving slab) in a daily routine at around 20°C. Here, too, it was identified that in the standard systems used in practice a peeling off is practically not possible until day 3. A testing within this time span shows how the peel-off resistance improves successively as curing progresses. However, this also means that thereafter a differentiation of individual systems is no longer possible.

Fig. 8 – Redirecting and peeling off a flexible film.

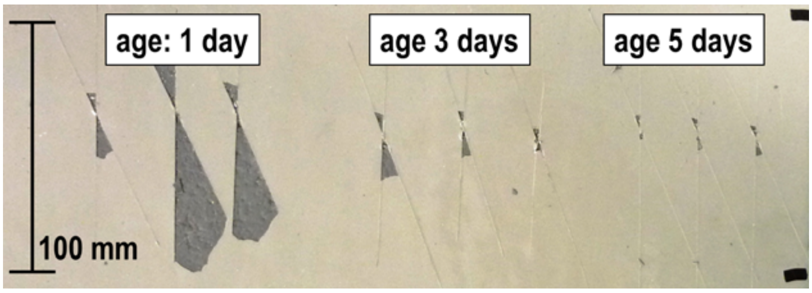

Fig. 9 – Improvement of the peel-off resistance *vs*.
the age of the system at the time of the test (20°C).

In falling temperatures this effect is delayed due to the slower curing process, comparable with the cross cutting. Besides, the peel-off resistance increases more slowly in polyurethanes than in epoxy-resin-based materials. This must be evaluated in context when tests are carried out on the project, *e.g.* PU top coats must be observed for at least 14 days when the ambient temperatures are low or until no more changes can be detected in the test results.

5.3. Tensile Strength

The tensile strength test for the interior shells of cooling towers is only a means of balancing, ≥1.0 N/mm^2; he must be achieved as according to VGB-Guideline (2010) as a mean value. The bonding of the overall system is evidenced by way of the cross cut.

Within the scope of the application technological tests the tensile strength values were also determined on all overall systems at 20°C and 50% rel. humidity. The substrate is the brushed back of paving stones, both with and without mineral levelling of the overall system.

Under these ideal conditions it was identified that the quality is for the most part independent of the coating systems used. Systems with levelling achieved on an average of 1.8 N/mm^2, while without levelling it was on an average of 2.9 N/mm^2. The age of the last top coat in the overall system fluctuated here between 3 and 14 days at the time of testing, however, this did not have any effect on the results. The tear-off was performed in 85% of all tests at the concrete substrate, using a mineral levelling in the contact area levelling – coating.

In one test series 18 individual samples each were examined with rolled on and sprayed on systems, respectively. Here, too, no influence on the tensile strength values could be detected (3.0 and 3.1 N/mm^2).

A correlation with the cross cut exists with regard to the generally weaker results when using mineral levelling. In flexible systems testing the peel-off resistance would be more effective, as here the tensile strength values would be disproportionally high due to the deformation of the coating system.

With regard to the tensile strength values as well, an age of the substrate/system to be tested of at least three days at 20°C and, respectively, longer waiting times at low temperatures would be preferable.

6. Conclusions

Of special importance is the time of testing, which does not yet produce reliable final results in particular during the first three days (relating to 20°C). Depending on system and weather this has to be checked, adjusted and if need be, repeated or extrapolated. At 8°C...10°C this then results in a waiting time of seven days (Table 4).

Furthermore, primarily the roughness of the surface must be taken into consideration, as the performance of cross cuts and acute angle cuts are less precise and variation increases as a result.

An achieved measurement must therefore never be treated as absolute in practice. For example, an insufficient cross cut in the context of a test time that is premature, the use of a polyurethane system, cold weather and a potential damage to the mineral levelling must be evaluated differently to a testing of an insufficient testing of an EP system after 7 days at around 20°C. In view of the usually large number of operators and the complex framework conditions of a cooling tower repair project the reliable basis of such knowledge is of particular importance. Decisions based on this basis can help save unnecessary costs.

Table 4
Overview of Influencing Parameters and Framework Conditions in the Testing of the Bonding

	Cross cut	Acute angle cut	Tensile strength*
Influence operator	high	high	moderate
Influence age (at 20°C)	up to three days high	up to three days high	up to three days high
Influence age (at 8°C)	up to seven days high	up to seven days high	up to seven days high
Influence levelling	high	high	high
Difference spray/roll application	none	none	none
Roughness	maximal fine-coarse	maximal fine-coarse	medium roughness
System component	intermediate coats and substrate	intermediate coats and substrate	intermediate coats and substrate
Maximal layer thickness	≤ 250 μm, (DIN EN ISO 2409, 2007)	can still be cut	–
Testing of flexible systems	suitable	highly suitable	not suitable
Limits	≤ G_{t1} G_{t2} still acceptable (VGB-Guideline, 2010)	mm^2 good, cm^2, still acceptable, dm^3, not acceptable**	≥ 1.5 N/mm^2 ≥ 1.0 N/mm^2 , (VGB-Guideline, 2010) only levelling

* Evaluation for overall systems, in accordance with VGB-Guideline (2010) only used for levelling.
** Rough estimation in accordance with results obtained by Engelfried (1991).

In addition to these fundamental aspects the extensive experience of all involved is necessary in order to also recognize small but significant details. To name just a couple of examples at this juncture: the influence of the tensile strength between masking tape and coating surface or the influence of the levelling on the test results.

Even if in future new or innovative systems are being used in practice it is still advisable to check and limit the above mentioned influencing parameters in the run up to the tests, so that the transferability to practical application can be made easier.

REFERENCES

Engelfried R., *Instandsetzung und Ertüchtigung von Stahlbetonkühltürmen*. VGB Kraftwerkstechnik, **71**, *12*, 1145-1146 (1991).

Engelfried R., *Surface Protection Measures in Cooling Tower Shells Operating with Flue Gas Desulfurization Plants of Coal Power Stations. Design and Execution Monitoring of Retro-Fits and New Constructions*. Proc. of the 4th Internat. Coll. Mater., Sci. A. Restor., TAE, **1**, 361et seq, 1996.

Heine P., *Oberflächenschutz von Kühlturminnenschalen – positive Langzeiterfahrungen mit Beschichtungssystemen*. Bautechnik, **87**, *7*, 418-423 (2010).

* * * *Coating Materials – Cross Cutting Testing*. DIN EN ISO 2409, 2007.

* * * *Guideline Protection and Repair of Concrete Structures*. Rili-SIB, 2001.

* * * *Measures in Cooling Towers and Chimneys Made from Reinforced Concrete for the Protection Against Operational and Environmental Impacts VGB-R 612*. VGB-Guideline, Third Issue, 2010.

TESTAREA ŞI EVALUAREA STABILITĂȚII SISTEMELOR DE IZOLARE ALE SUPRAFEȚEI INTERIOARE LA TURNURILE DE RĂCIRE

(Rezumat)

Turnurile de răcire cu tiraj natural constituie structuri industriale deosebite. Datorită suprafeței foarte mari care se află în contact permanent cu o mare diversitate a factorilor de impact între agenții de mediu şi mediul interior, membrana interioară a turnurilor de răcire necesită o protecție deosebită, constituind un caz particular. Aceasta este realizată prin aplicarea unui sistem de acoperire pe bază de rășină polimerică, asigurând o durabilitate crescută structurii din beton armat, care, în timp, asigură o durată de serviciu prelungită la un preț de întreținere scăzut. În vederea aplicării cu succes a protecției sunt stabilite etape preliminare privind testarea materialelor componente, tehnologiei de aplicare (incluzând aici şi testarea aderenței sistemului de protecție la stratul suport).